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EFFECT OF VACUUM EXHAUST PRESSURE ON THE PERFORMANCE OF MHD DUCTS AT HIGH B-FIELD

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Abstract

The effect of area ratio variation on the performance of a supersonic Hall MHD duct showed that for a given combustion pressure there exists an area ratio below which the power generating region of the duct is shock free and the power output increases linearly with the square of the magnetic field. For area ratios greater than this, a shock forms in the power generating region which moves upstream with increasing magnetic field strength resulting in a less rapid raise in the power output. The shock can be moved downstream by either increasing the combustion pressure or decreasing the exhaust pressure. The influence of these effects upon duct performance is presented in this paper.

Introduction

In early experiments in the high magnetic field strength, liquid-neon-cooled cryomagnet facility at the Lewis Research Center, a heat sink MHD Hall duct was tested at an area ratio of 2.56/1 and then rebored and tested at an area ratio of 4/1.[1-3] Besides the resulting increase in power with increased area ratio, the significant result has been the linear increase in power output with the square of the magnetic field. On the basis of these results and principally due to the fact that the duct was limited by design constraints to a maximum area ratio of 4, a new Hall duct was constructed. This duct allows a maximum area ratio of 6.25, is approximately 20% longer, and has a segmentation pitch one-half the size of the original duct. Three series of tests have been performed with this duct having area ratios of 4, 5, and 6.25, respectively. Test data at an area ratio of 4 agreed with that obtained in the original duct at this area ratio. At an area ratio of 5, the power output remained linear with B^2 and the maximum power output increased by approximately 30%. However, at an area ratio of 6.25, the power no longer increased with B^2, rising less rapidly at higher B-fields. This is the result of the choking of the channel which is seen from axial pressure profiles to move upstream with increasing B-field.

In reference 4, the effect of area ratio variation on the performance of a supersonic Hall MHD duct showed that for a given combustion pressure there exists an area ratio below which the power generating region of the duct is shock free. In this shock-free regime, the power output of the duct is found to increase linearly with the square of the magnetic field. For area ratios greater than this, a shock forms in the power generating region which moves upstream with increasing magnetic field strength resulting in a less rapid rise in the power output. Increasing the combustion pressure moves the shock back downstream and results in an increase in the performance of the duct up to a point where the decrease in electrical conductivity due to the increased pressure at the upstream end of the duct (fixed inlet area) overcomes the increase in power output due to the area ratio increase.

The peak performance of the duct for this series of tests[4] occurred at an area ratio of 5/1 for a combustion pressure of 150 psia. For this condition, 180 kW was generated which represents approximately a 2.5% enthalpy extraction. The reason that additional performance was not achieved in the 6.25/1 area ratio duct was due to shocks in the channel which required a combustion pressure of 170 psia to remove them. At this pressure, the reduction in electrical conductivity was sufficient that this operating configuration produced a power output somewhat below that obtained with the 5/1 area ratio duct at a combustion pressure of 150 psia. Therefore, in order to obtain improved performance with this duct, removal of the shocks without increasing the combustion pressure by operation with subatmospheric exhaust is necessary and the results of operation in this mode are the topic of this paper.

MHD Duct Construction

The original duct used in the 2.56/1 and 4/1 area ratio experiments is shown on the top half of figure 1. It basically consisted of four modules each made up of eight circular electrodes clamped together with two triangular-shaped end plates by three tie rods. The lateral alignment of the module was maintained by three fiberglas rods. This ten-electrode module has a segmentation pitch of 1.38 cm. The four modules are bolted together and two 2.22 cm triangular end plates are added to provide sufficient thickness for bolting to the combustor, nozzle and diffuser. The duct therefore consisted of 42 electrodes. A picture of this duct is shown in figure 2, and other details of the design are given in reference 1.

In the original duct, the area ratio was limited to a maximum of 4/1 mainly due to the temperature limitation on the fiberglas alignment rods and the surface available for the inter-electrode gaskets. In the new design, this problem was overcome by rotating the alignment rods 60 degrees relative to the tie rod holes, increasing the outer diameter of the circular electrodes from 15.2 cm to 17.8 cm, and rounding the sides of the triangular plates out to the edge of the 17.8 cm diameter circular electrodes as shown in the drawing on the lower half of figure 1. Also in order to reduce the possibility of interelectrode electrical breakdown, the segmentation pitch was reduced to 0.74 cm. The duct was then made up of five modules consisting of 16 circular electrodes clamped by three electrically isolated stainless steel tie bolts between two triangular electrodes at each end for a total of 20 electrodes/module. The copper electrodes are 0.64 cm wide and electrically insulated from one another by a high-temperature asbestos gasket 0.078 cm thick (to provide the pressure seal), sandwiched between two 0.013 cm thick sheets of mica (to provide the electrical insulation and moisture barrier). Lateral movement of the electrodes is negated by three fiberglas rods inserted through the entire module. Five such modules are used in the present experiments with

figures, the shock location is taken from the axial pressure distribution shown in figure 10. In figure 11, it is seen that for operation without the vacuum exhaust that the Hall voltage rises abruptly up to the point at which shock occurs and then rises much less steeply through the rest of the channel. In the case of operation with the vacuum exhaust, the shock has moved into the diffuser and no abrupt change in slope of the Hall voltage is observed. As the B-field is increased to 2.5 tesla (fig. 12), the shock moves upstream as does the abrupt slope transition point of the Hall voltage. Finally at a B-field of 4.5 tesla (fig. 13), the shock is driven upstream of the upstream power takeoff electrodes, and the entire power generating portion of the MHD duct is operating subsonically. In this case, no abrupt change in the slope of the Hall voltage is observed for the run with no vacuum exhaust.

In figure 14 the effect of vacuum exhaust operation at a combustion pressure of 150 psia is shown. In this figure the curve labeled "without vacuum" is reproduced from figure 5. The circular points are the data points for the "with vacuum" tests. As previously observed for a combustion pressure of 100 psia the effect of operating with exahust vacuum is to remove the shocks from the channel resulting in a linear power output with the square of the B-field. The peak power output in these tests was 195 kW, which corresponds to approximately 3% of the input enthalpy.

CONCLUDING REMARKS

Studies of the effect of area ratio variation on the performance of a supersonic Hall MHD duct have been extended to area ratios of 6.25/1 from the previous limit of 4/1 by the design and construction of a new duct. It has been shown that for a given combustion pressure there exists an area ratio below which the power generating region of the duct is shock free. In this shock-free regime, the power output of the duct is found to increase linearly with the square of the magnetic field. For area ratios greater than this, a shock forms in the power generating region which moves upstream with increasing magnetic field strength resulting in a less rapid rise in the power output. Increasing the combustion pressure moves the shock back downstream and results in an increase in the performance of the duct up to a point where the decrease in electrical conductivity due to the increased pressure at the upstream end of the duct (fixed inlet area) overcomes the increase in power output due to the area ratio increase. Operation of the system with vacuum exhuast moves the shock downstream of the power producing region of the duct and again results in a linear increase in power output with the square of the B-field.

References

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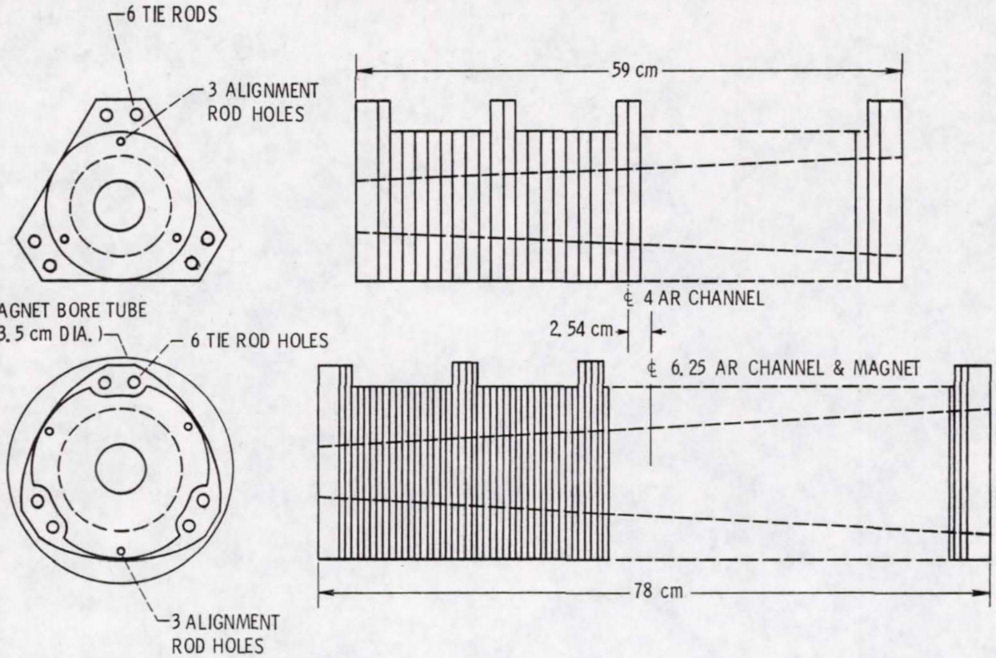

Figure 1. - Comparison of construction between 1.38 and 0.69 cm segmentation ducts.

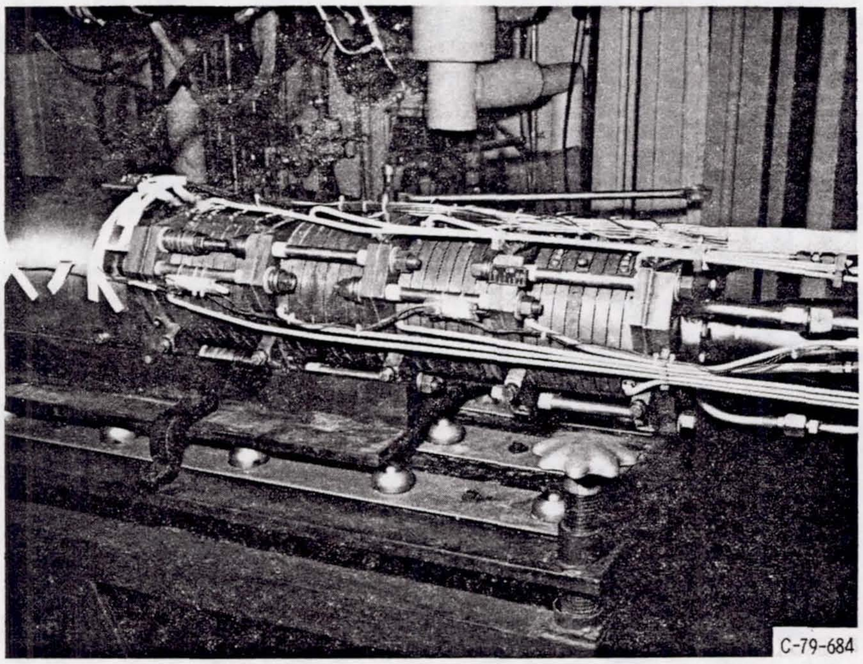

Figure 2. - 1.38 Segmentation ratio duct.

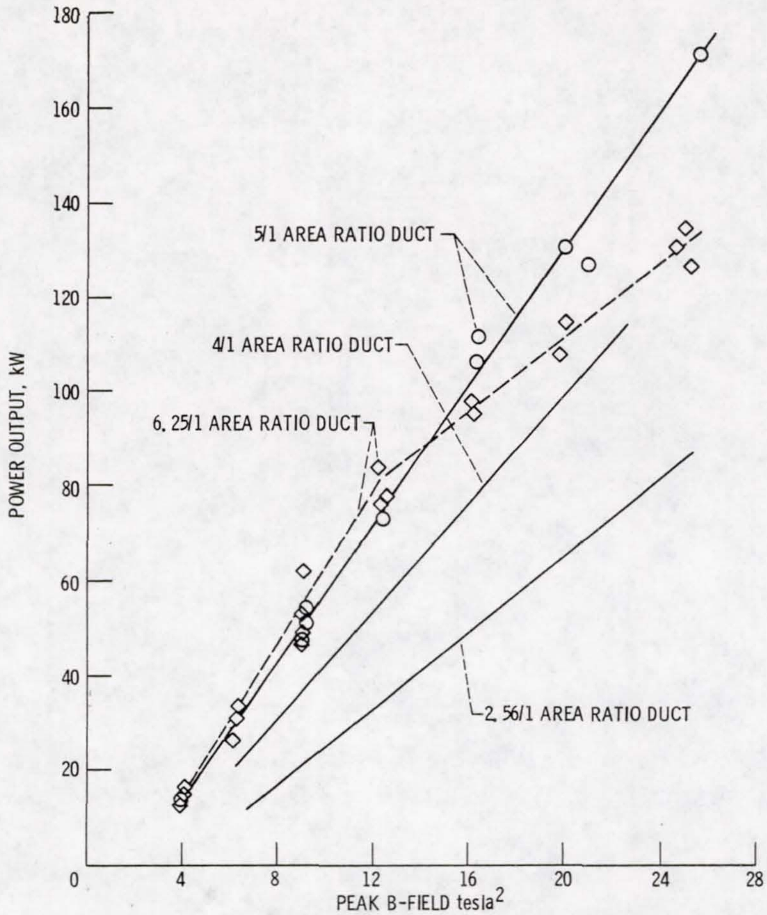

Figure 5. - Power output versus B-field squared as a function of duct area ratio for P_C = 150 psia.

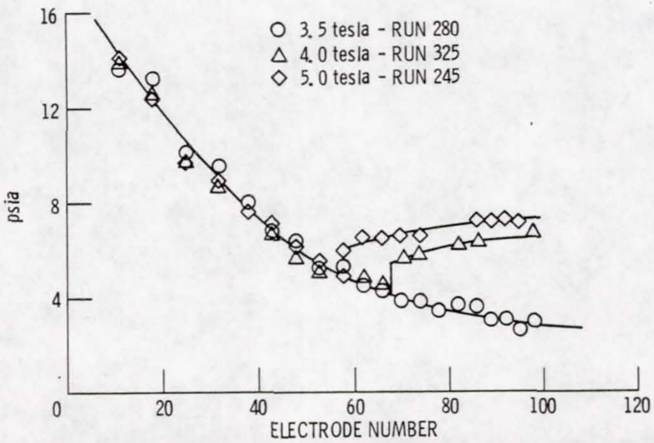

Figure 6. - Axial pressure distribution for an AR = 6. 25 and P_C = 150 psia as a function of B-field.

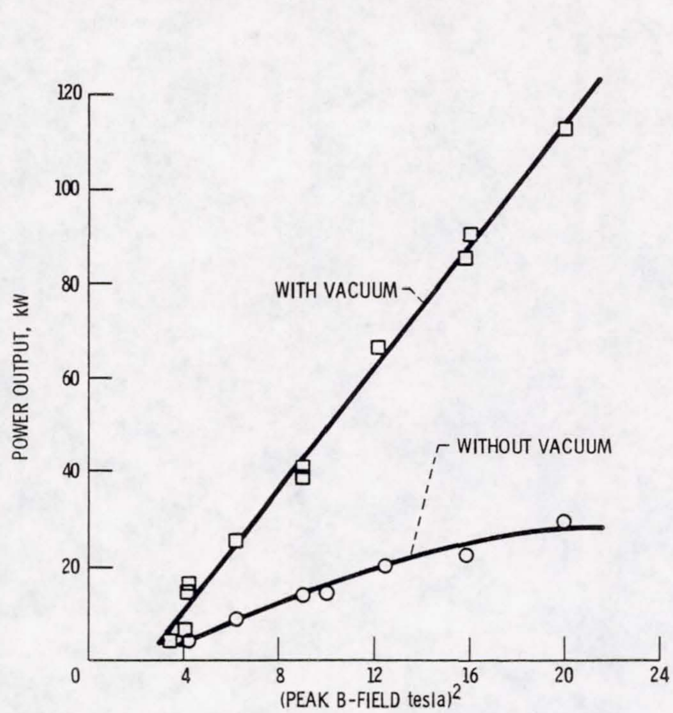

Figure 9. - Effect of vacuum exhaust upon power output versus B-field for AR = 6.25 and P_C = 100 psia.

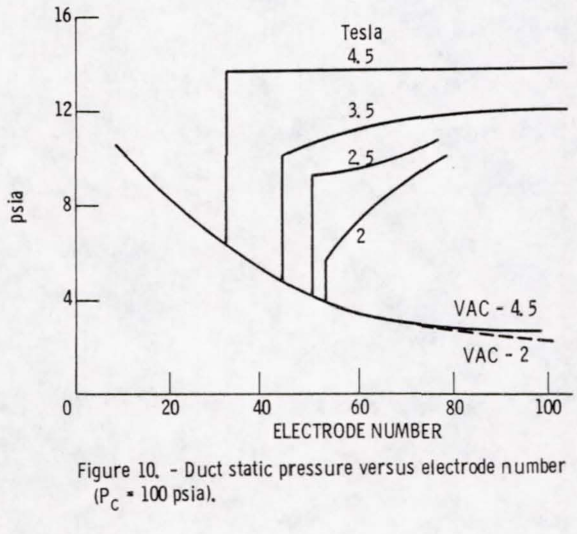

Figure 10. - Duct static pressure versus electrode number (P_C = 100 psia).

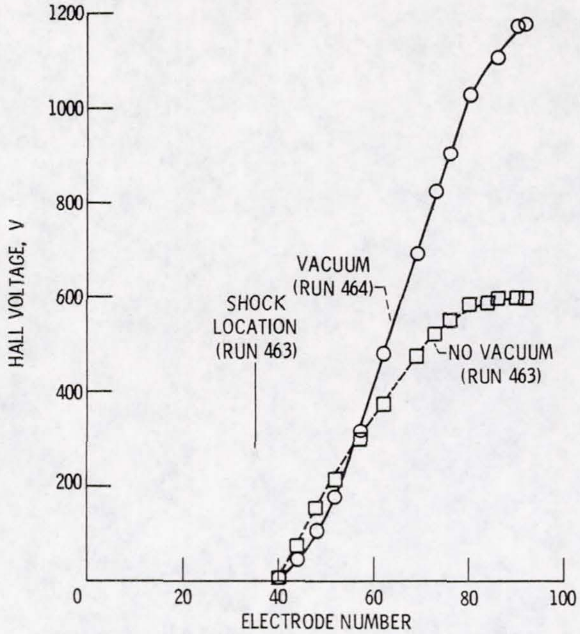

Figure 13. - Effect of vacuum exhaust on Hall voltage at 4.5 tesla (P_c = 100 psia).

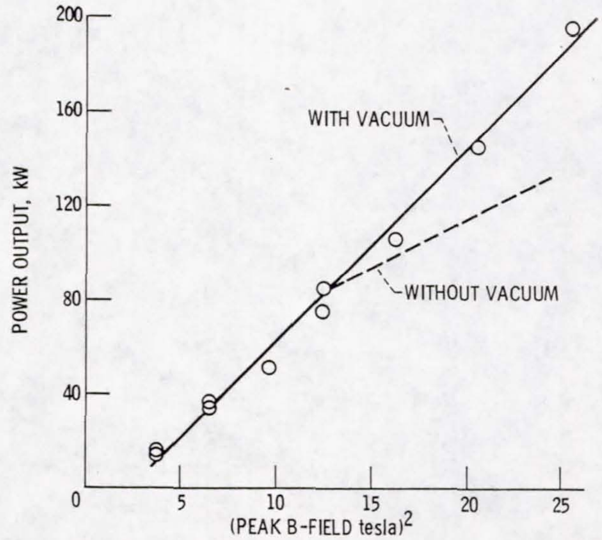

Figure 14.- Effect of vacuum exhaust upon power output versus B-field for AR = 6.25 and P_c = 150 psia.

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